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Thermal Effect of Thermal Energy Storage (TES) Tank for Solar Energy Application During Charging Cycle Based on the Grid Sensitivity Analysis.

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Abstract

Present design and engineering processes often rely on the simulation tools as the preliminary assessment or verification process of development. This is due to computational tools are naturally augmented by the sensitivity and uncertainty. As from the incomplete understanding of the input parameters, it is important and necessary to judge the reliability of the results. This is where the grid sensitivity play the role as the point of reference, verification and evaluation data. In this paper investigate the effect of grid sensitivity analysis based on level of mesh to the thermal effect of thermal energy storage (TES) tank for solar energy application during charging cycle. The experiment was performed with TES tank is using water as the working fluid and operated for 9 hours from 9 am to 6 pm with the volume flow rate of 13.2 L/min. The experiment resulted the temperature TES outlet is in the range of 45 to 65 °C. The experimental data is used in the simulation and the results is compared and discussed. The grid sensitivity analysis based on different level of mesh is simulated using CFD flow simulation. The simulation resulted the best initial mesh level to compare with experimental results is mesh level 5. The comparison of experimental and simulation using initial mesh level 5 resulted the percentage difference of 9.67%. In conclusion, the grid sensitivity analysis not only affect the thermal behaviour of the TES tank but also the computational time.

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Keywords: thermal energy storage; charging cycle; grid sensitivity analysis.

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1. Introduction

Reviews on sensitivity analysis methods have been conducted in variation of methods due to quantitative uncertainty analysis is currently prominent [1,2,3]. Some of the studies explicitly highlight the advantages and disadvantages of various methods and provide very good summaries of the topic. This analysis understanding is studied further, instead of only based on the simple evaluation of influence factors of an experimental [4].

These influence of different uncertainties of model factors on the modelling outcome, has become a key question [5]. Therefore, the source of uncertainties including parameters, boundary conditions, model structure, etc can be varied in the modelling process. This is very important if the aim is to minimize the uncertainties of a model when the resources and collecting data are limited [4].

This paper describes the purpose of grid sensitivity analysis has the effect on the flow pattern and the temperature distribution of TES tank [4].

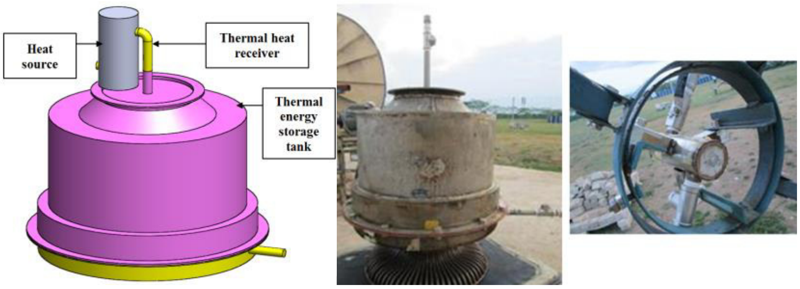
Nomenclature

ε	turbulence edge dissipation
h	enthalpy
PTD	percentage of temperature different
ρ	density
Q_H	heat flux
q_i	heat flow
S_i	strain rate
T_{TESE}	temperature of TES experimental
T_{TESS}	temperature of TES simulation
τ_{ij}	viscous shear stress tensor
τ_{ij}^{R}	Reynolds-stress tensor
$u_{i,j,k}$	fluid velocity in the direction of *i*-th, *j*-th and *k*-th
μ	viscosity coefficient
μ_l	dynamic viscosity coefficient
μ_t	turbulent eddy viscosity coefficient
$x_{i,j,k}$	spatial coordinate of *i*-th, *j*-th and *k*-th

2. TES Tank Charging Cycle

Thermal storage system is an energy saving device for later usage. The system is usually in a special designed tank and employed when encounter the inconsistency of energy supply and demand [6]. In this solar energy application, the solar radiation is focused to a thermal heat receiver (THR). The THR in the solar thermal system is used to intercept and absorb the reflected and concentrated solar radiation and transport/convert it to usable energy [7].

The TES tank system operated at two critical conditions; during the availability of sun and the unavailability of sun. Fig. 1 showed the diagram for the TES tank and THR. The method of testing will consists of three cycles; initial cycle, charge cycle and discharge cycle [8].



(a) (b) (c)

Fig. 1. (a) 3D model TES tank; (b) 3D model TES tank and THR; (c) 3D model cross section of TES tank and THR; (d) actual TES tank; (e) actual THR

The charge cycle varies the temperatures of HTF required to recharge the device agree, period by period, when input of supply heat delivered during the cycle. In the beginning, the storage device is in the state of discharge reached at the end of the discharged cycle test. The charge cycle test will determine the temperature of charging and heat charging capacity.

3. Methodology

3.1. Settings for grid sensitivity analysis in computational fluid dynamic (CFD) simulation

A model factor contributes to the sensitivity of a model outcome through variations of this factor alone and by interaction with other factors [4]. For the flow simulation, a commercial available CFD package is used. This CFD package will solve the fluid flow geometries using three main equations which are the formulations of mass, momentum and energy conservation laws for fluid flows. The equations are supplemented by the fluid state equations, defining the conditions of the fluid and empirical laws for the dependency of viscosity and thermal conductivity on other flow parameters [9].

The conservation laws for mass, angular momentum and energy in Cartesian coordinate system rotating with angular velocity Ω about an axis passing through the coordinate system's origin can be written in the conservation forms as follows [9,10,11]:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i) = 0 \tag{1}$$

$$\frac{\partial \rho u_i}{\partial t} + \frac{\partial}{\partial x_j}(\rho u_i u_j) + \frac{\partial p}{\partial x_i} = \frac{\partial}{\partial x_j}(\tau_{ij} + \tau_{ij}^R) + S_i i = 1,2,3 \tag{2}$$

$$\frac{\partial \rho H}{\partial t} + \frac{\partial \rho u_i H}{\partial x_i} = \frac{\partial}{\partial x_j}(u_j(\tau_{ij} + \tau_{ij}^R) + q_i) + \frac{\partial p}{\partial t} - \tau_{ij}^R \frac{\partial u_i}{\partial x_j} + \rho\varepsilon + S_i u_i + Q_H, \tag{3}$$

$$H = h + \frac{u^2}{2} \tag{4}$$

Following Newtonian fluids the viscous shear stress tensor is defined as:

$$\tau_{ij} = u\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\delta_{ij}\frac{\partial u_k}{\partial x_k}\right) \tag{5}$$

Following Boussinesq assumption, the Reynolds-stress tensor has the following from:

$$\tau_{ij}^R = u_t\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\delta_{ij}\frac{\partial u_k}{\partial x_k}\right) - \frac{2}{3}\rho k \delta_{ij} \tag{6}$$

Where

$$\mu = \mu_l + \mu_t \tag{7}$$

and μ_l is the dynamic viscosity coefficient and μ_t is the turbulent eddy viscosity coefficient. In this paper, the CFD simulation generated 3D model needs to be simple yet representative to minimize iteration time. By using the design in Fig. 1, the boundary conditions are set as in Table 1.

Table 1. Boundary conditions setting for fluid flow simulation

Boundary Conditions	Type	Value
Inlet thermal heat receiver	Inlet volume flow rate (L/min)	13.2
Outlet TES tank	Environment pressure (Pa)	101325
Heat Source	Temperature (K)	Varied 673.2 to 1073.2
Initial mesh	1 to 8	

3.2. Design of experiments (DOE)

The charge cycle as defined by ANSI/AHRI Standard 900 (IP)-2010 will varied the temperatures of HTF required to recharge the device, period by period, when input of supply heat delivered during the cycle. The charging cycle by solar heat supply by means shall maintain the HTF temperature at 40 $^\circ C$ to 65 $^\circ C$.

As the apparatus in Fig. 2 is arranged, the motor is turned on and the ball valve is adjusted to change the flow rate of the HTF in TES tank. In this study, the charging cycle using solar heat supply applied when the 2 m parabolic dish is used to focus the solar radiation towards the thermal heat receiver. The 2m parabolic dish is set at every 10 minutes and the direct normal irradiance (DNI) data is measured. This system is operated and observed from 9 am until 6pm.

The results of simulation is compared with the experimental results during charging cycle. The comparison of both results expected the temperature difference percentage as in Figure 2.

Temperature difference percentage is calculated as:

$$PTD = \frac{T_{TESE} - T_{TESS}}{\left(\frac{T_{TESE} + T_{TESS}}{2}\right)} \times 100 \tag{8}$$

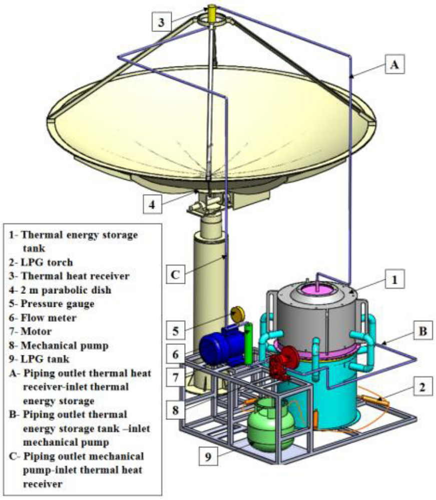


Fig. 2. Apparatus arrangement for experiment testing.

4. Results & Discussions

4.1. Grid sensitivity analysis

This grid sensitivity analysis was performed based on mesh sizes; coarse and fine mesh [12]. Based on the CFD simulation, the result of mesh is showed in Fig. 3 (a). The figure differentiate the mesh occurred by the fluid cells in the region of X_{min}= -0.465 m, X_{max}= 0.146 m, Y_{min}= -0.528 m, Y_{max}= -0.096 m, Z_{min}= -0.190 m and Z_{max}= 0.364 m. By referring to the figure, the size mesh of the fluid cell in the TES tank is converged to finer grid from Mesh 1 to Mesh 8. This figure indicates limited dependence of the results on the grid solution.

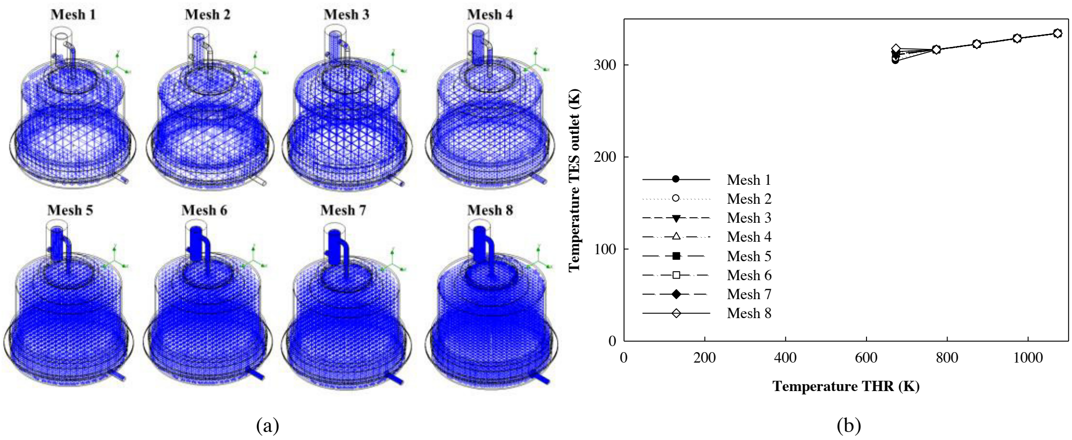


Fig. 3. (a) Mesh results by using different mesh level (b) Effect of temperature TES outlet at different temperature THR for different mesh level.

From the figure, the temperature output of TES tank is extracted and plotted in the Fig. 3(b). Based on the graph showed in Fig. 3(b) indicates the effect of temperature output of the TES tank at different temperature of THR for different initial mesh value with the volume flow rate of 13.2 L/min. The pattern of the graph is increasing as the value of initial mesh is increased. By referring to the plotted values in range of 773 K to 1073 K, the value of temperature TES outlet is increasing deficiently. This is due to the initial mesh value, as the initial mesh value increasing the temperature TES output will converge and at some point will results in constant value. By comparing the results from the simulation and experimental, it can be seen that the nearest compatible value is using initial mesh value of 5. Performing a grid-sensitivity analysis is important to reduce the discretization errors and the computational time [12].

4.2. Thermal effect of TES tank

The experiment is conducted and performed at Faculty of Mechanical Engineering in Universiti Malaysia Pahang (Pekan Campus) on 9th April 2014. Based on the results of experimental, the value of temperature THR gained is set as the input value of temperature THR in the simulation.

Fig.4 showed the effect of temperature TES outlet and DNI over time at volume flow rate of 13.2 L/min for experimental and simulation. From the graph, at Hour 1100 and Hour 1400 is due to cloudy situation that affect the decrement of DNI, temperature TES outlet and temperature of THR. Different case results for Hour 1800, the decrement of the DNI, temperature TES outlet and temperature of THR is due to sunset.

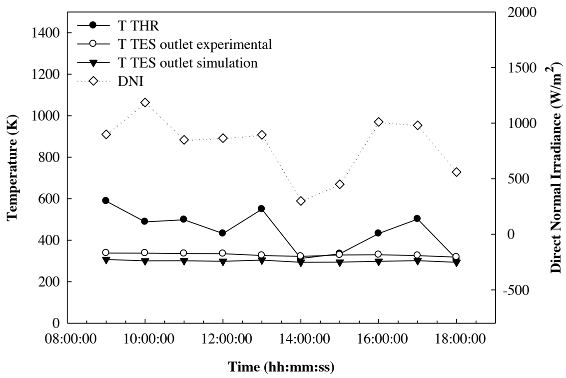


Fig. 4. Effect of temperature and direct normal irradiance over time on 9th April 2014.

By using the equation (7), the PTD of temperature TES outlet simulation is slightly lower of 9.67% than experimental data. The difference is due to the environmental condition considerations in the simulation whereby the condition in simulation is the ideal condition [13].

5. Conclusion

The grid sensitivity analysis of thermal effect on TES tank for solar energy technology during charging is investigated in this paper using the commercial CFD tools. The results show the pattern of mesh and temperature TES outlet. Then, the experiment is carried out to validate the data on the temperature outlet.

All of the results is further analysed and discussed. The simulation and experimental results affirm well. In consequence, this study is useful in order to reduce the discretization errors and the computational time of simulation. For further development, the same input could be used to study the fluid effect in TES tank.

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